Force feedback device / force properties

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Force feedback devices are, at first sight, a category of haptic devices that are able to exert a controlled force by the means of actuators in their mechanical (or gesture) interaction with a user. This definition, provided for the sake of simplicity, should be considered carefully [→ Haptics, haptic devices] [→ Force feedback]. Anyhow, the expression force feedback device clearly relates with the idea of a controlled force. Hence, an important mean to evaluate these devices consists in considering their force properties.

Force properties of force feedback devices can be decomposed in three categories:

- The sizing properties of the force produced in the real world by the haptic device. These consist mainly in continuous force and peak force.
- The properties of the image of the real force in the virtual world, i.e. the "virtual" force.
- The relation between the real force and the virtual force. This can be analyzed for non-temporal properties through force resolution, force accuracy and for temporal properties through force response.

Sizing criteria: Continuous force and Peak force

The electromagnetic actuators implemented by force feedback devices necessarily present intrinsic limitations. Generally speaking, the force sizing criteria refers to the specific properties of the electromagnetic actuators. This leads to define two different maximum forces: a continuous force (the maximum force that can be applied for an unlimited period of time without taking damage) and a peak force (the maximum feasible force).

The continuous force of a device is always smaller than its peak force. Often, avoiding a possible overheating of the actuators limits the continuous force: the device driver has to reduce the force when temperature reaches a critical value. Typical values for the continuous force of haptic devices lay between 1.5 Newton for the PHANToM [Massie et al, 1994], more than 100 Newton for the light-weight robot, or 80 Newton for each axis of the ERGOS [Florens et al 04] system.

The peak force is the maximum force that a device can generate during a short period of time. In general, devices operate far below their peak force. Its value is determined by the physical limits of the device or by the power control.

Finally, one can note that for serial-linked devices, the joint torques depend on the device configuration and on changes inside the workspace, even when the load remains constant. Instead of continuous and peak force, one should consider continuous torque and peak torque.

Real/virtual force relation: Non-temporal properties

Firstly, force resolution is related to the quantization step of the force: the smallest change in the actual force that can be exerted or detected.

Force quantization is caused most often by the use of digital technology (e.g. analog-to-digital converters). Designers of haptic devices should take into account the just noticeable difference (JND) for force – i.e. the limit of humans regarding the perception of a change in a force. To allow the device to display smooth changes in the force, the actuator resolution should be higher than the JND. Noticeably, the JND in forces follows the Weber-Fechner law: it decreases with the total force - it is about, indeed, 5-10% of the total force [Allins et al, 2002]. This is an important practical problem for force feedback devices, because in most of them, due to a fundamental limit in the technology, the force resolution is constant over the possible force range.

As for it, force accuracy is defined as the maximum error that exists between the command (or represented) force value to be applied, and the actually displayed force. Hence, force accuracy is a rough description of the force error. The nature and signal characteristics of the various components in the error must be considered to evaluate their relative importance. A particularly important aspect of force error signal is, indeed, its correlation with the corresponding axis motion. Force errors that consist in additional energy source like resolution errors are much more perceptible than passive forces, like the biases in the cinematic model. In a lesser importance, the passive force errors that are correlated to motion by hard non-linearity like the actuator saturation error may be also perceptible.

Real/virtual force relation: temporal properties of force response

Depending on the type of control mode of the device at hand, the part of the device to consider here is either its force sensing chain (in admittance mode), or its force actuation chain (in impedance mode).

In the case of sensing (admittance mode), in practice, the temporal response is not really limited by the sensor itself, since it is generally based on resistive or piezzo-electric gages. It is mostly limited by the sensor's localization inside the mechanical chain. Indeed, the inertia and elasticities that are situated between the users' contact point and the sensor create a low pass filtering effect in the transfer of the sensed force.

In the impedance mode, the force actuation chain is generally based on a local force control loop, because no actuating device is able to provide a satisfactory force actuation in a complete open loop mode. As a consequence, the transfer properties of the global actuation chain depend mainly on the force sensing properties of the local force control loop involved.

However, in some cases, the effective force sensing is replaced by a motor current sensing. This configuration is generally referred as open loop force actuation, or as open loop impedance mode. In this case, the power of the electro-magnetic motor plays the role of force sensor. This results in several limitations concerning the force transfer: (1) the force transfer gain depends on the parameters of the power device, which may vary in time; and (2) the response is affected by the position of the force sensing point in the mechanical chain. In particular, the response is biased by the inertial and friction forces generated by such a mechanical chain.

Properties of the virtual forces

The properties of the virtual force computed depend mainly on the category of modelling employed.

In the context of spatio-geometrical modelling, the haptic interface is introduced as an additional "display" of a pre-existing geometric model. The dominant methodology consists in completing the existing model by an additional algorithm dedicated to the computation of the force and to the control of the haptic interface [→ Haptic rendering of virtual objects].

Another approach consists in using a natively physical model [→ Physically-based modelling techniques for multisensory simulation]. In this case, the forces computations are inherently taken into account by the model. No specific force response algorithms have to be considered.

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